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The objective of this research was to study the mechanisms of transient radiation by various antenna structures, and to apply to understanding gained to the design of new, better transient antennas. The approach chosen for this research program was to extend the finite-difference time-domain (FDTD) numerical method to antenna analysis and to use the developed methodology to study/design transient antennas.

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- J. G. Maloney and G. S. Smith, "The Use of Surface Impedance Concepts in the Finite-Difference Time-Domain Method," *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 1, pp. 38-48, Jan. 1992.
- J. G. Maloney and G. S. Smith, "The Efficient Modeling of Thin Material Sheets in the Finite-Difference Time-Domain (FDTD) Method," *IEEE Transactions on Antennas and Propagation*, Vol. 40, no. 3, pp. 323-330, Mar. 1992.
- J. G. Maloney and G. S. Smith, "Optimization of Pulse Radiation from a Simple Antenna Using Resistive Loading," *Microwave and Optical Technology Letters*, vol. 5, no. 7, pp. 299-303, June 1992.
- J. G. Maloney and G. S. Smith, "A Study of Transient Radiation from the Wu-King Resistive Monopole - FDTD Analysis and Experimental Measurements," submitted for publication to *IEEE Transactions on Antennas and Propagation*.

- J. G. Maloney and G. S. Smith, "A Comparison of Methods for Modeling Electrically-Thin Dielectric and Conducting Sheets in the Finite-Difference Time-Domain (FDTD) Method," submitted for publication to *IEEE Transactions on Antennas and Propagation.*
- J. G. Maloney and G. S. Smith, "Optimization of a Conical Antenna for Pulse Radiation: An Efficient Design Using Resistive Loading," submitted for publication to *IEEE Transactions on Antennas and Propagation.*

Conference Papers

- J. G. Maloney, G. S. Smith, and W. R. Scott, Jr., "Accurate Computation of the Radiation from Simple Antennas Using the Finite-Difference Time-Domain Method," *Proc. 1989 IEEE AP-S Int. Symp.*, San Jose, CA, June 1989, vol. 1, pp. 42-45.
- J. G. Maloney and G. S. Smith, "Implementation of Surface Impedance Concepts in the Finite-Difference Time-Domain (FD-TD) Technique," *Proc. 1990 IEEE AP-S Int. Symp.*, Dallas, TX, May 1990, vol. 4, pp. 1628-1631.
- J. G. Maloney and G. S. Smith, "The Role of Resistance in Broadband, Pulse-Distortionless Antennas," *Proc. 1991 IEEE AP-S Int. Symp.*, London, Ontario, June 1991, vol. 2, pp. 707-710.
- J. G. Maloney and G. S. Smith, "Optimization of a Resistively Loaded Conical Antenna for Pulse Radiation," *Proc. 1992 IEEE AP-S Int. Symp.*, Chicago, IL, July 20-24, vol. 4, pp. 1968-1971.
- J. G. Maloney and G. S. Smith, "A Discussion of Efficient Methods for Including Thin Material Sheets in the FDTD Technique," *Proc. 1992 IEEE AP-S Int. Symp.*, Chicago, IL, July 20-24, vol. 3, pp. 1666-1669.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS PERIOD:

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OUTLINE OF RESEARCH FINDINGS

The objective of this research was to study the mechanisms of transient radiation by various antenna structures, and to apply to understanding gained to the design of new, better transient antennas. The approach chosen for this research program was to extend the finite-difference time-domain (FDTD) numerical method to antenna analysis and to use the developed methodology to study/design transient antennas.

While it is difficult to quantify the performance of antennas used for pulse radiation, it is generally accepted that these antennas should have the following characteristics.

- The radiated pulse should be a faithful reproduction of the excitation; i.e., there should be little pulse distortion on radiation.
- The reflected signal at the input of the antenna should be small.
- The amplitude of the radiated signal in the desired direction should be as large as possible.

These characteristics were the standards by which transient antenna designs were judged.

Prior to this research program, the FDTD method had been widely and successfully used for scattering and interaction problems (mainly the calculation of target RCS); however, there had been little or no application to driven antenna problems. Therefore, the first task of this research program was to investigate the application of this method to driven antenna problems. The investigation began by applying the method to the calculation of the behavior of a few perfectly conducting antennas: the cylindrical and conical monopole antennas fed through an image plane by a coaxial transmission line. The FDTD results were validated by comparison with the experimental results of previous researchers. The level of agreement between the FDTD predicted behavior and the experimental results was excellent. Furthermore, various graphical displays, i.e, surface charge density "bounce" diagrams, gray scale plots of the near-field, "burst" diagrams of the time-domain far-field radiation, were used and proved very useful in describing the transient radiation from these antennas.

Transient antennas usually incorporate regions of resistive material into their structure. The resistive material can be categorized into two types: electrically thick and electrically thin. However, the direct modeling of these types of resistive material in the FDTD method is highly inefficient. Therefore, the next step in this research program was to develop efficient methods for modeling these types of resistive material.

The electrically thick case was considered first. Historically, electromagnetic problems involving electrically-thick resistive material are simplified by replacing the electrically-thick resistive material with a surface impedance boundary condition (SIBC). Therefore, the approach taken was to develop an efficient FDTD implementation of surface impedance concepts. The developed methodology was verified by comparison with exact theoretical results for several test problems. The problems included plane wave reflection off of a lossy dielectric half space, a pulsed wire over a lossy dielectric half space, and propagation down a parallel-plate waveguide with lossy walls. The FDTD predicted behavior for these three problems was in excellent agreement with the exact results.

As the "proof of concept" for this research program, the above described methodology was used in the "optimization" of the transient radiation of a canonical antenna: the open-ended parallel-plate waveguide. The walls of the antenna were made lossy/resistive over a section of the waveguide near the open-end. The FDTD computed results were used in a parametric study to determine the optimum resistive loading. The parametric study yielded a design that had a good radiated pulse shape, a small reflected signal, and an acceptable radiation efficiency; that is, the three criteria mentioned above were met. Again, various graphical displays were used to describe the transient radiation of this structure.

Of course, the open-ended parallel-plate radiator is a two-dimensional antenna; hence, it is unrealizable in practice. However, the methodology developed for optimizing the performance of this idealized antenna is applicable to more complex, practical three-dimensional antennas as will be shown below.

The next step in this research program was to consider the modeling of electrically-thin resistive material. Of course, the FDTD method could be used to directly model the electrically-thin material using very small FDTD spatial cells; however, this is very inefficient. The approach taken in the development of an efficient method was to consider a sub-cell model for the electrically-thin material. That is, a coarse spatial grid (large spatial cells) is used in the FDTD method with the few cells that contain the electrically-thin material being modified to include the effects of the material. Again, the developed methodology was verified by comparison with exact theoretical results for several test problems. The test configuration was a parallel-plate waveguide loaded with a thin resistive sheet. Results for both TEM and TM_1 excitation were in excellent agreement with the exact results. In addition to being able to model resistive sheets, the sub-cell model can be used to model thin-dielectric sheets. The results for dielectric sheets were also in excellent agreement with the exact results.

The first antenna application of the sub-cell model for electrically-thin resistive material was the study of the transient radiation from resistively loaded, cylindrical monopole antennas. Specifically, the transient radiation from the tapered resistive cylindrical monopole proposed by Wu and King in 1965 was studied. Again, various graphical displays were used to describe the transient radiation from the antenna. A series of experimental models of resistively loaded monopoles were constructed and the experimental measurements were in excellent agreement with the FDTD predicted behavior.

The final step in this research program was to design a new, practical transient radiator. The structure considered was the resistively loaded conical monopole antenna. The resistive loading was again optimized by performing a parametric study. In comparison with the performance of a perfectly conducting conical monopole, the "optimized" resistive design had internal reflections reduced by 35 dB, had a superior pulse shape, and had the same radiated amplitude; that is, the three design criteria mentioned earlier were met. Again, a series of experimental models were constructed, and the experimental measurements were in excellent agreement with the FDTD predicted behavior, thus, confirming the "optimization".

In addition to the application to resistive antenna analysis, the efficient techniques developed for modeling electrically-thin and thick material can be used in many other applications. Other applications to which the electrically-thin material model can be applied include: thin resistive films or cloths used in waveguide components and absorbers; thin, substrate mounted, metallic or dielectric films used in integrated circuitry; or thin dielectric windows or radomes used to enclose antennas. Other applications to which the electrically-thick material model can be applied include: non-perfect (lossy) conductors found in various transmission lines; or the non-perfect (lossy) conductors found in various high-Q resonators.

The research described above has resulted in seven journal papers and five conference presentations to date.